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NATURAL SCIENCES IN THE HIGHER SCHOOLS OF GERMANY

II.

THE first installment of this essay was devoted chiefly to the teaching of natural history in the first six years of the secondary schools. Inasmuch as the age of the pupils in *Sexta* is between nine and ten years, the greater part of the course would correspond to the upper primary and grammar school course in American schools. The work in physics and chemistry in the German schools corresponds more nearly to our high school standards.

The following outline of the course in physics and chemistry is from the programme of the *Königstädtisches Realgymnasium*, Berlin, 1895-6:

UNTERSECUNDA: *Physics*, 3 hours. First semester: Frictional electricity, and phenomena out of the domain of magnetism and galvanic electricity. Acoustics and optics. Second semester: Mechanics of solid, liquid, and gaseous bodies. General properties of matter. Parallelogram of forces and of motion. Laws of falling and vertically projected bodies. The simple machines. —— Text-book, Jochmann, *Grundriss der Experimental Physik*.

OBERSECUNDA: *Physics*, 3 hours. First semester: Magnetism and galvanic electricty. Second semester: Heat. Repetition and extension of mechanics, especially of oblique projection and of central motion. —— Text-book, same as in *Untersecunda*.

OBERSECUNDA: *Chemistry*, 2 hours. First semester: Discussion of the elements hydrogen, oxygen, nitrogen, chlorine, bromine, iodine, fluorine, in connection with experiments suitably selected. Foundation of the conception of element, compound, base, acid, and salt. The law of Marriotte and Gay-

Lussac [the gas law, PV=RT], the law of combination by weight and by volume [law of Gay-Lussac], the hypothesis of Avogardo, the molecule, the atom, valance. The regular [isometric] system (magnetite, rocksalt, fluorspar), the quadratic [tetragonal] system (cassiterite). Angle measurement with the goniometer, the solution of stoichiometrical problems. Second semester: Discussion of the elements sulphur, phosphorus, arsenic, boron, carbon, and silicon with experiments. Extension of the crystallographic idea. The orthorhombic and monoclinic systems (sulphur). Dimorphism, allotropism; the rhombohedral system (calcite, quartz). Angle measurement with the goniometer. Solution of stoichiometrical problems.

UNTERPRIMA: *Physics*, 3 hours. First semester: Wave theory, acoustics, and optics. Second semester: Mechanics. In both semesters, reviews and more thorough mathematical treatment of particular parts of the earlier work. Solution of problems. —— Text-book, same as in *Untersecunda*. (Physical laboratory exercises, 2 hours, optional.)

UNTERPRIMA: *Chemistry*, 2 hours. First semester: Discussion of the elements potassium, sodium, calcium, barium, strontium, and magnesium, with experiments. Vapor density. Volumetric analysis. Extension of the crystalographic idea (hemihedrism, twinning, isomorphism, pseudomorphism. The physical appearance of crystals). Manufacture of gunpowder, production of salt, soda, chalk, and gypsum. Angle measurement with the reflection goniometer. Solution of stroichiometrical problems. Second semester: Discussion of the elements of zinc, lead, iron, copper, manganese, cobalt, nickel, chromium. The law of Dulong and Petit. Extension of the crystallographic idea. The monoclinic system (green vitriol). The triclinic system (blue vitriol). Metallurgy of ores of lead, zinc, iron, and copper. Solution of stoichiometrical problems. Technological excursions. Work in the chemical laboratory. Illustration of preparations. Qualitative analysis by the "wet" method. Blowpipe analysis ("dry" method). Physical experiments important for chemistry.

OBERPRIMA: *Physics*, 3 hours. First semester: Optics. Second semester: Mechanics. In both semesters, reviews and more thorough discussion of parts of the earlier work, especially quantitative determinations and methods of measurement.——Text-book, same as above. (Physical laboratory exercises, 2 hours, optional.)

OBERPRIMA: *Chemistry*, 2 hours. First semester: Discussion of the elements tin, aluminum, antimony, bismuth, mercury, silver, gold, platinum, with experiments. Manufacture of alum. Periodicity of the elements. Solution of stoichiometrical problems. Work in the chemical laboratory. Illustration of preparations. Some quantitative determinations. Volumetric analysis. Second semester: Introduction to organic chemistry. Elementary ("ultimate") analysis. Acids, alcohols, aromatic substances, carbohydrates,

fermentation, albuminates, organic synthesis. Chemical theories. Manufacture of paper, starch, and sugar. General view of the natural processes of the organic world (germination, food assimilation, respiration, decomposition, putrefaction). Solution of stoichiometrical problems. Technological excursions. (Work in the chemical laboratory. Illustrations of organic preparations; determination of sugar by chemical and optical methods, 2 hours, optional.)

This outline leaves little to be said on the subject-matter of instruction in physics and chemistry. The aim in the teaching of physics, as in natural history, is not so much acquaintance with a large number of facts as the cultivation of the pupil's ability to make accurate observations and the development of his logical powers, chiefly with reference to the causal relations existing between particular natural phenomena. In this respect the *Real*-schools can show better results than the *Gymnasien*. But in all schools the government emphasizes the need of scientific observation confirmed and strengthened by a certain amount of formal practice.

According to the Prussian syllabus of 1892 the course in physics is divided into two parts. The first part is intended to give the pupil some notion of the fundamental principles of the subject as exemplified in the ordinary and more familiar manifestations of nature; it is concluded with *Untersecunda*. The continuation of the course aims to give those who may pass on to the university a more comprehensive understanding of physical laws and their applications. This division is in strict accord with a prevailing idea of the Berlin Congress, that those leaving school at sixteen should have as symmetrical training as is possible to provide. Only the most important principles are taught in the first part of the course, and much stress is put upon the application of these to the practical affairs of everyday life.[1]

The advanced course is first of all a repetition and extension of the earlier work, and in the second place a more extended mathematical treatment of the subject. This latter phase of the work can be done successfully only in the *Real*-schools, inas-

[1] Full information of what may be accomplished in this preliminary course may be found in the *Zeitschrift für den physikalischen und chemischen Unterricht, Jahrgang V*, Heft 4 (April, 1892).

much as the mathematics taught in most *Gymnasien* is insufficient for the purpose. The *Realgymnasium* of Weimar, for example, provides a special course in mathematics during the last two years devoted exclusively to mechanics. Particular attention is given to mathematical geography and the elements of astronomy.

It is only in the *Oberrealschulen* that a special course in chemistry is given in *Untersecunda*. Other schools are requested to present a few important chemical facts in connection with the study of galvanic electricity. At best but little can be done. Organic chemistry and its applications are practically untouched in all schools; any consideration whatever of the subject must be purely incidental, and confined to those processes of greatest practical importance.

Stoichiometry is the one branch of chemistry which is thoroughly taught, and it is the mathematical treatment of this branch which receives most attention. Mineralogy is a side issue; so far as I have observed, it amounts to little more than a formal study of crystallography.

A text-book is always employed in teaching physics and chemistry precisely in the same manner as in teaching natural history. But unlike the methods commonly found in American and English schools, German teachers invariably use these books for reference only. It is not expected, however, that they will take the place of the elaborate compendiums found in each schoolroom; they are mere outlines of the subject intended to assist the pupil in making scientific classifications, not for purposes of recitation. In fact, as we have repeatedly observed, the German teacher never assigns a lesson in advance to be studied out at home. Recitations, therefore, at least in the American sense, are unknown.

A typical lesson always includes a review of the principles and experiments of past lessons which have a direct bearing upon what is next to be presented. The teacher explains the nature of the apparatus with which he is to deal, and places it upon his desk in full view of the entire class. (It may be observed in passing that schoolhouses of recent construction have a lecture

room for the classes in physics and chemistry in which the seats are elevated, generally in a semicircle about the teacher's desk.) Certain conditions are stated and the class questioned as to what results may reasonably be expected. This preliminary discussion having carefully prepared the way for a right understanding of the experiment, the demonstration by the teacher follows. The students are required to make note of the apparatus used, the principles involved, the conditions under which the reaction occurred, and the results obtained. By means of a running fire of questions the teacher keeps himself informed in regard to the mental state of his class, for it is his duty to see not only that all understand the trend of the experiment, but also that its significance is realized.

German practice is always consistent in its adherence to the idea that good teaching never leaves the pupil in doubt. In mathematics he is not assigned a problem to wrestle with by himself alone; in the early days of his language study all of the translations are made in class; and even in natural history we have seen how he is guided, step by step, first in making his observations and then in describing what he has discovered.

We observe the same facts in the prevailing methods of teaching physics and chemistry. Every principle worth demonstrating is illustrated in class. But the teacher does more than demonstrate; he *teaches* as well. And successful teaching requires that present impressions be definitely related to past experiences. Wrong relationships, or none at all, are an inevitable consequence of misapprehension. For this reason the German teacher counts it his duty to prevent his students drawing wrong inferences. They have not yet arrived at the stage of independent study; that comes in the university. In the secondary schools no time should be wasted in beating about the bush. The ability to make an occasional lucky guess is in no wise identical with sustained logical thought.

At the conclusion of a lesson topic the pupil is directed to consult his text-book and afterwards write up his notes. This done the teacher inspects the books at his leisure.

Laboratory exercises, if required at all, are introduced at this point in order that students may themselves duplicate the experiment performed by the teacher, or make other demonstrations putting to practical test the knowledge just acquired. The function of laboratory practice, as will be seen, is to make application of facts already learned, not at all for the purpose of presenting new truths or arriving at new deductions. Inasmuch as laboratory practice is optional, and the exigencies of the time card usually place it out of school hours, few students enter for it. No harm is done, however, if only a part of the class avail themselves of the opportunity. They learn something thereby, to be sure, but their previous knowledge is intensified rather than extended. In other words the certainty of promotion is not jeopardized by failure to elect the laboratory course.

Probably the best adducible evidence of the relative value of the various studies, as popularly estimated, is the part each plays in the final examination. Judged in this way the sciences take low rank. Physics may be counted as a fourth part of mathematics in the gymnasial examination; in the *Real*-schools one problem is assigned in physics and one in chemistry.[1]

The worst of it is that "nothing short of a miracle," to quote a German teacher, "can prevent the promotion of the most deficient member of the class provided his attainments be satisfactory in other subjects."

[1] The problems in science assigned at the *Abiturientenprüfung* in the *Königstadtisches Realgymnasium*, Berlin, were as follows:

Physics, Michaelmas, 1895. "To determine the internal resistance of a Bunsen battery cell the following experiments are made:

a) In one arm of a Wheatstone's bridge a resistance of one ohm is inserted; in the other arm, a rheostat. The galvanometer needle shows no deviation when the rheostat resistance, $r_1 = 4.5$ turns of the wire.

b) There is now introduced into one arm of the bridge a copper wire whose length, $l = 9.8$ meters; and whose thickness, $d = 1$ millimeter; and again in the other arm, the rheostat. The galvanometer needle now shows no deviation when the rheostat resistance, $r_2 = 0.84$ turns of the wire.

c) Through the same copper wire and through a tangent galvanometer (joined in series) a current is led by means of the Bunsen cell under investigation. The needle of the tangent-galvanometer now shows a deviation, $\alpha_1 = 17° \ 30'$.

d) A second and like Bunsen cell is now introduced into the circuit in series with the first. The needle now shows a deviation, $\alpha_2 = 25°$.

How great according to these experiments, is the internal resistance of a Bunsen cell?

In conclusion it need hardly be said that the teaching of science in the German secondary schools is intended primarily to provide formal discipline of the powers of observation, of logical thought and accurate description. Evidence is not wanting to show that the sciences are not taught as distinct subjects, but as a means of assisting the individual to a more complete realization of his environment. Pedagogic writers emphasize repeatedly the futility of attempting to give the preparatory student a thorough knowledge of the principles even of a single science; this is the work of the university. The aim of the secondary schools should be to provide such training as will enable the student when he enters upon his university career to begin the study of any science intelligently. In other words, an understanding of the relations existing between sciences is of more worth than an extensive knowledge of any one. Therefore, the principles of biology and of physics properly taught are the sole requisite for entrance upon university work. The physical conditions under which life develops are an important accessory to the study of biology, and the principles of chemistry supplement advantageously the teachings of physics.

The presence of laboratories well equipped for individual work and supported by annual appropriations in most German schools, shows that the present method of science teaching is a reaction against earlier notions concerning the function of laboratory practice. So long as the aim was to teach the sciences *per se*, laboratory work was necessary for each individual, but with the advent of the idea that the sciences are no more to be considered independent studies than other subjects of the curriculum, and that mental development of the pupil is of more consequence than definite information in any one subject, class

Further, how great, according to the experimental results obtained, is the specific resistance of copper?

The above experiments — especially the arrangement and mode of operation of the Wheatstone's bridge — are to be described and explained by means of a simple diagrammatic figure.

Chemistry, Easter, 1896. "The description of the most important chemical and crystallographic properties of silicic acid, and the explanation of its importance in the plant and animal kingdoms with some examples."

instruction at once comes into the foreground. Laboratory work is still counted an exercise of great value, but its aim is to facilitate application rather than to promote individual investigation. The right use of the inductive method by no means shifts the responsibility from the teacher to the pupil. The teacher must do even more teaching; in fact the pupil can be more safely trusted to work independently along deductive lines than inductive. But as I have repeatedly cautioned the reader not to confound class instruction with the hearing of a recitation, no one will identify the German method of teaching science with certain practices well-nigh universal in America.

We may criticise the methods of the German teacher how we will; we may disapprove of his selection of subject-matter, his apparatus, laboratory and text-book; and especially we may refuse to recognize the legitimacy of his aim and the worth of his ideals; and yet when all is said the German teacher has some convincing arguments in store. He can point triumphantly to a long line of German scientists, once his pupils. He will tell us that all students entering the university are familiar with at least the elements of physical and biological science, that this work has been an integral part of their school training for nine years; that the classical students are broadened by contact with the *real* studies, and that the scientific men are more liberal for having included the humanities in their education. The clinching argument, however—an argument convincing at least to the commercial world—is that the marvelous industrial progress of Germany in the last quarter century is due ultimately to the superior skill and wisdom of the German scientists. England today—witness the recent action of the government in promoting the teaching of science and the resolutions of learned societies and trade unions—is assured that the preservation of her supremacy in the markets of the world is largely dependent on her ability to train up such scientists as now direct the development of the industrial arts in Germany.

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